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Strange quark distribution and corrections due to
shadowing and isospin symmetry breaking

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Abstract

The strange sea quarks distributions of nucleons obtained by two global analyses based on available structure function data of muon and neutrino deep inelastic scatterings are different from the strange sea quark distribution measured by the CCFR Collaboration from dimuon events in neutrino scattering. We discuss possible contributions to this discrepancy from the nuclear shadowing in the deuteron and from the isospin symmetry breaking in the sea between the neutron and the proton.

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The global analyses of quark distributions of nucleons are undergoing rapid progress due to the increased precision of deep inelastic lepton scattering data [1]. The New Muon Collaboration (NMC) data on $F_2^{p,d}$ from muon scattering [2] and Columbia-Chicago-Fermilab-Rochester (CCFR) data on $F_{2,3}^{Fe}$ from neutrino and antineutrino scatterings [3] have been used by the CTEQ Collaboration [4] and the Durham-RAL group (MRS) [5] in their global analyses of quark distributions. The new strange sea quark distributions are found to be larger than those of earlier fits. A strange quark distribution from a leading-order QCD analysis of opposite-sign dimuon events induced by neutrino scattering has been presented by the CCFR Collaboration recently [6]. From Fig. 1, where the CCFR, CTEQ and MRS results of strange quark distribution are presented, we see that there is a discrepancy between the strange quark distribution from dimuon events in neutrino scattering and those of the global analyses. We will discuss in this paper the contributions to this discrepancy from the nuclear shadowing effect in the deuteron and from the isospin symmetry breaking in the sea between

the neutron and proton.

The CTEQ and MRS global analyses are mainly based on data of structure functions from muon deep inelastic scattering on protons and deuterium, and from neutrino deep inelastic scattering on nuclear targets, which when expressed in terms of quark distributions, read

$$F_2^{\mu p} - F_2^{\mu n} = \frac{1}{3}x(u + \bar{u} - d - \bar{d}); \quad (1)$$

$$F_2^{\mu d} = \frac{1}{2}(F_2^{\mu p} + F_2^{\mu n}) = \frac{5}{18}x(u + \bar{u} + d + \bar{d} + \frac{4}{5}s); \quad (2)$$

$$F_2^{\nu d} = \frac{1}{2}(F_2^{\nu D} + F_2^{\bar{\nu} D}) = x(u + \bar{u} + d + \bar{d} + 2s); \quad (3)$$

$$xF_3^{\nu d} = \frac{1}{2}x(F_3^{\nu D} + F_3^{\bar{\nu} D}) = x(u - \bar{u} + d - \bar{d}), \quad (4)$$

where $F_{2,3}^{\nu d}$ are converted from $F_{2,3}^{\nu Fe}$ using a heavy-target correction factor, with $F_{2,3}^D$ denoting $\frac{1}{2}(F_{2,3}^p + F_{2,3}^n)$. These four observables determine four combinations of parton distributions, which can be taken to be $u + \bar{u}$, $d + \bar{d}$, $\bar{u} + \bar{d}$ and s by assuming $s(x) = \bar{s}(x)$. From Eqs. (2) and (3), we obtain the equality

$$\frac{5}{6}F_2^{\nu d}(x) - 3F_2^{\mu d}(x) = xs(x). \quad (5)$$

The CTEQ Collaboration also plotted the quantity on the left-hand side of this equation at $Q^2 = 5 \text{ GeV}^2$ using data from NMC and CCFR, as shown in Fig. 1. We thus know that the large strange quark distributions in both

the CTEQ and MRS global analyses are natural results of the data of the muon structure function of deuterium and the neutrino structure function $F_2^{\nu d}$ converted from $F_2^{\nu Fe}$. The smaller MRS strange quark distribution compared to that of CTEQ is due to a renormalization factor 0.94 for the CCFR structure function data. We will show, in the following, that several nuclear effects could contribute to the right-hand side of Eq. (5).

We first consider the nuclear shadowing correction in the deuteron structure function

$$F_2^{\mu d} = \frac{1}{2}(F_2^{\mu p} + F_2^{\mu n} + \Delta F_2^{\mu d}), \quad (6)$$

which was chosen to ignore the shadowing term $\Delta F_2^{\mu d}$ and assumed to be Eq. (2) by NMC, CTEQ, and MRS. The sign of $\Delta F_2^{\mu d}$ is negative, thus it contributes positively to the left-hand side of Eq. (5). There have been several theoretical works on the shadowing correction in the deuteron with different predictions about the magnitude [7]-[9]. One work [7] has suggested a significant amount of shadowing in the deuteron (up to 4% for $x \simeq 0.01$), whereas other calculations have predicted less dramatic effects (2% in Ref. [8] and 1% in Ref. [9]). In Fig. 1 we present our calculated $\frac{3}{2}\Delta F_2^{\mu d}$ following Ref. [7], which gives the most large theoretical estimate among available works. We see that this most large estimate is of about 30% of the strange

quark distribution measured by CCFR, and it can explain the discrepancy between the results by CCFR dimuon measurement and by MRS. However, it is too small to explain the discrepancy between the results by CCFR and by CTEQ.

Then we analyse the corrections due to isospin symmetry breaking in the neutrino structure function $F_2^{\nu d}$, which was converted by CTEQ and MRS from CCFR $F_2^{\nu Fe}$ data using a heavy-target correction factor. Actually the CCFR $F_2^{\nu Fe}$ data were from a combination of neutrino and antineutrino data and it should be $F_2^{\nu Fe} + F_2^{\bar{\nu} Fe}$. Thus $F_2^{\nu d}$ should be expressed by

$$F_2^{\nu d}(x) = (ZF_2^{\nu p} + NF_2^{\nu n})/A = \frac{1}{2}(F_2^{\nu p} + F_2^{\nu n}) + \frac{I}{2}(F_2^{\nu n} - F_2^{\nu p}), \quad (7)$$

where $I = (N - Z)/A$ is the isotopic asymmetry parameter for Fe. If we assume isospin symmetry between the proton and the neutron, i.e.,

$$F_2^{\nu p}(x) = F_2^{\nu n}(x), \quad (8)$$

we can express $F_2^{\nu d}$ by

$$F_2^{\nu d}(x) = \frac{1}{2}(F_2^{\nu p} + F_2^{\nu n}), \quad (9)$$

which is Eq. (3). However, it has been suggested [10] that the isospin symmetry breaking could be an alternative source for the Gottfried sum rule violation reported by the New Muon Collaboration (NMC) [11]. This means

that there are more sea quark in neutrons than in protons, while the u- and d- sea symmetry is still preserved. In this case we have

$$F_2^{\nu n}(x) - F_2^{\nu p}(x) = 4x[O_q^n(x) - O_q^p(x)], \quad (10)$$

where $O_q^{n,p}(x) = \bar{u}^{n,p}(x) = \bar{d}^{n,p}(x)$ are the u- and d- sea quark distribution in neutrons and protons. Because $O_q^n(x) - O_q^p(x)$ is positive, it contributes positively to the left-hand side of Eq. (5). From Ref. [10] we know that we need

$$\int_0^1 dx [O_q^n(x) - O_q^p(x)] = 0.084 \quad (11)$$

to reproduced the observed Gottfried sum $S_G = 0.240$ reported by NMC, by neglecting the shadowing correction in deuterium. If we take the shadowing correction as adopted above, we need

$$\int_0^1 dx [O_q^n(x) - O_q^p(x)] = 0.165 \quad (12)$$

to reproduced the observed S_G . This will give a larger correction to the left-hand side of Eq. (5). To estimate the magnitude of the correction, we adopted a non-Pomeron form correction $O_q^n(x) - O_q^p(x) = a(1-x)^b$, which has been analyzed [12] to study the proton-induced Drell-Yan production data of the Fermilab experiment E772 [13] in the isospin breaking explanation for the Gottfried sum rule violation. By choosing $b = 25$, with a adjusted to satisfy Eq. (12), we can still reproduce the E772 data for the ratio

of cross section $R = \sigma_W/\sigma_{IS}$ and for the shape of the differential cross section $m^3 d^2\sigma/dx_F dm$ for ^2H . In Fig. 1 we present the calculated $\frac{I}{2}(F_2^{\nu n} - F_2^{\nu p})$ due to isospin symmetry breaking. We find that the correction is of about 4% of the strange quark distribution measured by CCFR. It is too small to explain the discrepancy between the results by CCFR dimuon measurement and by CTEQ and MRS global analyses.

We now check the heavy-target correction factor $A(x)$ which is used to convert $F_2^{\nu Fe}(x)$ to $F_2^{\nu d}(x)$; i.e.,

$$F_2^{\nu d}(x) = A(x)F_2^{\nu Fe}(x). \quad (13)$$

Both CTEQ and MRS have adopted the correction factor $A(x)$ by taking into account nuclear effects based on the muon iron/deuterium structure function ratios observed by EMC, NMC *et al.*. The exact correction factor $A(x)$ used by MRS is presented in Tab. I of Ref. [5], with a further normalization factor 0.94. $A(x)$ used by CTEQ is expressed by

$$A(x) = 1/R(x) = [1.118 - 0.4199x - 0.3597\exp(-22.88x) + 1.872x^{11.27}]^{-1}, \quad (14)$$

where $R(x)$ is a parametrization of the NMC measurement of Ca/D_2 and the SLAC result for Fe/D_2 . We see that both the nuclear shadowing effect and the EMC effect have been considered in $A(x)$. We indicate here that an

assumption of the absence of shadowing in neutrino scattering will reduce $F_2^{\nu d}$ by an amount of $(A(x)-1)F_2^{\nu Fe}$ at small x . In Fig. 1 we present the two points of the data $\frac{5}{6}(A(x)-1)F_2^{\nu Fe}(x)$. We see that the magnitude of the two points are comparable with the difference of the strange quark distribution parametrized by CTEQ and that by CCFR dimuon measurement. However, the shadowing is expected also to occur in neutrino scattering and there have been available WA59 data indicating a shadowing compatible with predictions [14]. The renormalization factor 0.94 in the MRS analysis is large and important at small x , as can be seen Fig. 1. This is the reason for the large difference between the CTEQ and MRS results of strange quark distributions. However, this normalization correction seems to be suitable at small x , but too large at larger x .

One conclusion from our work is that it is of essential importance to consider all possible corrections due to nuclear effects in the available experimental data, for good and reliable global analyses of quark distributions. It has been discussed in this paper two possible contributions to the discrepancy between the strange quark distributions obtained by two global analyses and the strange quark distribution measured by the CCFR Collaboration from dimuon events in neutrino scattering. The shadowing in the deuteron and the isospin symmetry breaking in the sea between the neutron

and proton could provide some corrections, but are still too small to explain the discrepancy. This suggests that new mechanism is needed to solve the conflict between the strange quark distributions of the global analyses and those by the CCFR Collaboration from dimuon events in neutrino scattering. An attempt to explain this conflict has been proposed recently as due to the strangeness quark and antiquark asymmetry in the nucleon sea and will be given elsewhere [15].

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Figure Captions

Fig. 1. The results of strange quark distribution $xs(x)$ as a function of the Bjorken scaling variable x . The \bullet points are the CCFR data from dimuon events in neutrino scattering for $Q^2 \approx 5 \text{ GeV}^2$. The \circ points are the CTEQ “data” of $\frac{5}{6}F_2^{\nu d}(x)(\text{CCFR}) - 3F_2^{\mu d}(x)(\text{NMC})$. The thick and thin solid curves are the CTEQ and MRS parametrizations of $xs(x)$ for $Q^2 = 5 \text{ GeV}^2$. The dashed and dotted curves are corrections due to the large shadowing effect in $F_2^{\mu d}(x)$ and the isospin symmetry breaking in $F_2^{\nu d}(x)$. The \oplus points are corrections from assuming the absence of shadowing effect in neutrino scattering. The dash-dotted curve is the correction due to the normalization factor 0.94 for the MRS global analysis.

Fig. 1 by B. Ma

